Materials Science & Engineering A 589 (2014) 97–100

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Effect of plate-like alumina on the properties of alumina ceramics prepared by gel-casting

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ARTICLE INFO

Article history:
Received 24 June 2013
Received in revised form
15 September 2013
Accepted 18 September 2013
Available online 25 September 2013

Keywords:
Plate-like alumina
Gel-casting
Viscosity
Fracture toughness

ABSTRACT

In this work, alumina ceramics were prepared via gel-casting by mixing plate-like and granular alumina powders. Plate-like alumina with a hexagonal or disk-shaped morphology decreased the viscosity of the suspension remarkably, which made the casting process much easier. As the plate-like alumina content varied from 10 wt%, 30 wt%, 50 wt%, 70 wt% to 100 wt%, the density and bending strength of the sintered ceramics increased firstly then decreased and reached their maximum at the content of 50 wt%. However, the microhardness and fracture toughness presented negligible dependence on plate-like alumina content. It is worth noting that all samples with plate-like alumina displayed lower density and bending strength but higher fracture toughness than the sample without plate-like alumina.

1. Introduction

Excellent properties of alumina, such as chemical, thermal stability, high strength, high hardness, wear resistance, make it can be applied in various engineering field [1]. However, its lack of reliability and low fracture toughness limits its application [2]. Gel-casting has been considered as a promising method to fabricate complex-shaped alumina components due to its advantages such as controllable casting, rapid forming cycle, minimal molding defects, fabricating green bodies with high mechanical strength and stiffness, low shrinkage during drying and sintering processes, and ability to process complex-shaped and near-net-shaped ceramic parts [3–5]. In gel-casting process, the suspension slurry with high solid loading and low viscosity is crucial for high-quality ceramics [6]. But the solid loading and viscosity are contradictory for gel-casting: high solid loading inevitably leads to high viscosity if granular alumina powders are used as raw materials [7].

In this work, we try to obtain high solid loading and low viscosity suspension slurry for gel-casting by using plate-like alumina as raw materials. Plate-like alumina is a single crystal of α-Al_2O_3 with a hexagonal or disk-shaped morphology [8]. The radial dimension and thickness of plate-like alumina are in micron and nano-scales, respectively. Therefore, it has dual performances of both micron powder and nano powders, which are appropriate for surface activity and good adhesion. It can easily combine with an active group without agglomerate [9]. Plate-like alumina is supposed to improve the fluidity of the slurry. Meanwhile, plate-like grains have been reported to improve fracture toughness due to form crack bridging easily in ceramics [10–13]. We prepared alumina ceramics via gel-casting with plate-like alumina powder contents ranging from 0 to 100 wt% to investigate the effects of plate-like alumina on the microstructure and mechanical properties of alumina ceramics.

2. Experimental

2.1. Materials and processing

Commercially available granular alumina (α-Al_2O_3, d_{50}=2.02 μm) and plate-like alumina (α-Al_2O_3, diameter of 3 μm, thickness of 0.5 μm) powders were used as the starting materials. Six batches were mixed using the two powders and additives containing Y_2O_3 and MgO. The relative contents of plate-like alumina powder in these batches were 0, 10, 30, 50, 70 and 100 wt%. The essential reagents in gel-casting are commercially available, including monomers: acrylamide, $C_2H_3CONH_2$ (AM) and N,N′-methylenebisacrylamide, $(C_2H_3CONH)_2CH_2$ (MBAM); initiator: ammonium bisulfate $(NH_4)_2S_2O_8$ (APS); catalyst: N,N,N′,N′-tetramethy-lenediamine, $(CH_3)_2N(CH_2)_2N(CH_3)_2$ (TEMED); dispersant: ammonium polyacrylate (PAA–NH_4). All reagents were chemically pure.

A premixed solution of monomers was prepared in deionized water with an appropriate amount of AM and MBAM. Six batches of ceramic powders with 2 wt% dispersant were mixed in the premixed solution. The suspensions were mechanically stirred for

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http://dx.doi.org/10.1016/j.msea.2013.09.061

at least 1 h and degassed for 10 min until no bubbles were released. The initiator and catalyst were then added. Afterwards, the slurry was cast into a mold. After gelation, the green body was demolded and dried at room temperature. Finally, the green compacts were sintered at 1800 °C in air. A flow chart of the process is shown in Fig. 1.

2.2. Testing methods

The rheological properties of the slurries were determined using a rotational viscometer (NXS-11B, China) at a constant temperature of 25 °C. The bulk densities of the samples were measured by the Archimedes' method. The sintered specimens with a dimension of 3 mm × 4 mm × 30 mm were ground and polished to test. The flexural strength was measured by three-point bending test with a span of 13.10 mm at a crosshead speed of 0.5 mm/min. The micro hardness was measured on the polished surfaces by using a diamond pyramid indenter at a load of 300 N and a loading duration of 10 s. Fracture toughness value (KIC) was measured by indentation test on Wilson-wolpert Tukon 2100B (INSTRON), and the load and loading time were 49 N and 10 s, respectively. The morphology of dispersed powders and the microstructure of the fracture surface were observed with scanning electron microscope (LEO1450 SEM) after the samples were coated with carbon.

3. Results and discussions

The SEM micrographs of plate-like alumina and granular alumina particles are shown in Fig. 2. The plate-like alumina powders have a hexagonal platelet shape, an approximate thickness of 0.5 μm, and size of 3 μm. The granular alumina powders have a granular morphology, with an average particle size of 2.02 μm.

Six slurries with 50 vol% solids loading were prepared with mixed granular and plate-like alumina powders as raw materials. The relative contents of plate-like alumina powder changed from 0, 10 wt%, 30 wt%, 50 wt%, 70 wt% to 100 wt%. Fig. 3 shows the effect of the plate-like alumina content on the viscosity of the suspensions. All the suspensions exhibit a shear-thinning behavior which is beneficial for the slurry casting. The viscosity of the suspension is largely influenced by the plate-like alumina. With the increase of plate-like alumina content, the viscosity of the suspensions rapidly decreases. As can be seen, at 20 s^{-1} shear rate, with the plate-like alumina content increase from 0 to 100 wt%, the viscosity of the suspensions decrease from 1105 mPa · s to 224 mPa · s. The fluidity of the slurry is improved significantly with the addition of plate-like alumina.

The mechanical properties of alumina ceramics with different plate-like alumina powder contents are shown in Table 1. It is observed that the density of the sintered ceramic increases firstly, reaching the maximum value of 3.88 g/cm^3 at 50 wt% plate-like alumina content, and then decreases to 3.28 g/cm^3. This phenomenon can be attributed to the larger grain size of plate-like alumina with lower sintering activity [8]. The variation of the bending strength is in accordance with the density. As the plate-like

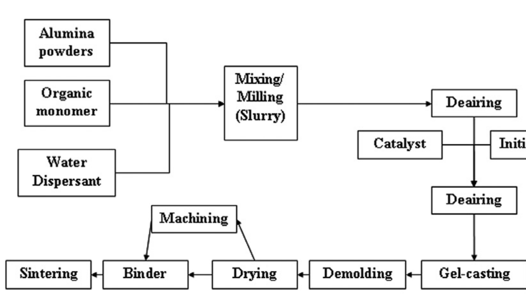

Fig. 1. Flow chart of the preparation of alumina ceramic.

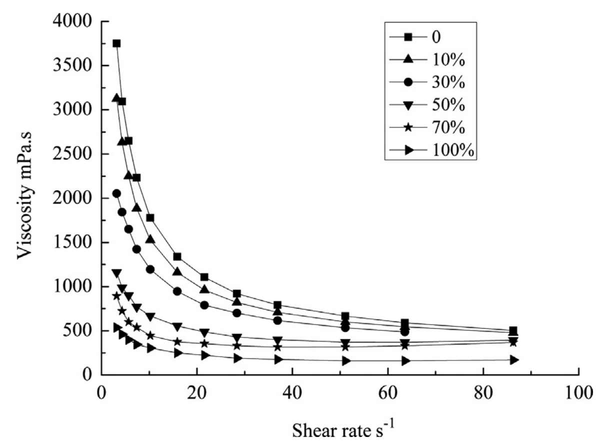

Fig. 3. Effect of plate-like alumina content on the viscosity of suspensions.

Table 1
Experimental results.

Plate-like alumina content	Density g/cm^3	Bending strength MPa	Micro hardness GPa	Fracture toughness MPa m$^{1/2}$
0	3.93	310.82	10.66	3.16
10%	3.60	196.80	12.97	3.57
30%	3.71	225.90	11.62	3.51
50%	3.88	264.16	10.09	3.58
70%	3.28	124.50	13.44	3.50
100%	3.33	160.49	12.24	3.36

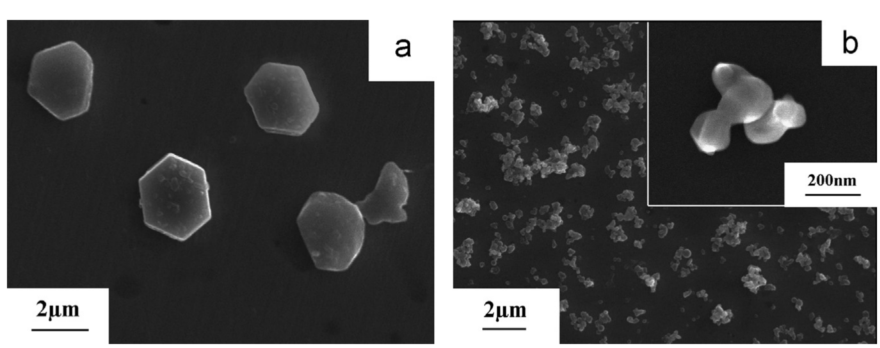

Fig. 2. SEM micrograph of plate-like alumina (a) and granular alumina (b) particles.